AD P001752

IMPACT AND PENETRATION OF LAYERED PAVEMENT SYSTEMS

THOMAS E. BRETZ, JR.
AIR FORCE ENGINEERING AND SERVICES CENTER
TYNDALL AIR FORCE BASE, FLORIDA

PHILLIP T. NASH
SOUTHWEST RESEARCH INSTITUTE
SAN ANTONIO, TEXAS

ABSTRACT

The Air Force is sponsoring research on damage-resistant runway designs. The designs are based upon principles which use high strength/high density materials to resist weapon momentum. Initially, two subscale pavement sections will be designed, one representing a rigid pavement for long-term aircraft traffic, and the other representing a redundant surface to withstand limited aircraft operations. The penetration resistance for both pavement sections will be determined experimentally. Penetration-resistant layers of rock or concrete rubble will then be designed as a sub-base to the pavement sections and these designs will be tested at subscale. Testing full-scale penetration-resistant rubble layers will be accomplished, and concept development should be complete in the late 1980s.

BACKGROUND

The United States Air Force is vitally concerned with airbase recovery following a conventional air attack. One area in which a great deal of research and development is occurring is rapid runway repair (RRR). Two technical areas of research and development in the Air Force RRR Program Office are rapid crater repair and alternate launch and recovery surfaces (ALRS). In the rapid crater repair technical area, engineers are developing procedures to rapidly repair bomb craters. In the ALRS technical area, engineers are developing methods to construct alternate airfield pavements which will provide the capability to operate aircraft while the initial craters in the main runway are being repaired. These alternate pavements will be constructed during peacetime.

There are two aspects to the ALRS technical area. One is based on pavement redundancy. The idea here is to construct large areas of aircraft operating surfaces that are redundant to the main runway(s). These redundant surfaces need only withstand a limited amount of fighter traffic since the surfaces are intended to function only until the main operating surface is repaired. The other aspect of the ALRS technical area is based on construction of hardened runways that, when attacked, will sustain only limited damage which can be quickly repaired. This is particularly important for airbases that have insufficient land area for construction of vast areas of redundant surfaces. The hardened or damage-resistant runway research will be discussed below.

OBJECTIVE

The objective of the damage resistant runway research is to develop methods to construct runway surfaces that are less subject to bomb damage than existing surfaces. The term, "less subject," is based on time to repair. The time to repair damage in a damage-resistant runway must be less than 30 minutes per crater. Concepts for damage-resistant runways must be economically feasible for construction and must be compatible with aircraft and aircraft operations. Payoff from the damage-resistant runway research is expected in the late 1980's.

RESEARCH PROGRAM

The Air Force Engineering and Services Center is sponsoring a research effort by the Southwest Research Institute to develop a concept for construction of hardened runways. The research is being performed to determine the ability of a layer of rock rubble or boulders placed beneath a pavement's surface to cause penetration path disruption or weapon malfunction.

Background

During the attack of the Nicosia International Airport in 1974, damage created by 750-pound bombs was far less than expected [1]. Decreased damage was attributed to a hard cap rock located at

an average of 4-5 feet below the runway surface. In general, the bombs did not penetrate the cap rock and, therefore, detonated at shallow depths resulting in small diameter (12-24 feet), shallow (3-5 feet) craters. Many of the bombs either deflagrated or failed to function at all. Rock rubble overlays have proven effective as a means of defeating kinetic energy penetrators attacking protective shelters [2,3]. When properly sized, initial penetration resistance of the rock rubble closely duplicates the resistance of a semi-infinite mass of rock. If opposed by adequate resistance, penetrating bombs do not perform to full potential and result in much smaller craters, thus requiring significantly less repair time.

Technical Approach

The design parameters important to this study are shown in Figure 1. Although Figure 1 is not all inclusive in detail, it does illustrate the principles involved. Details are described below:

Weapon Threat - 500-pound class general purpose bomb;

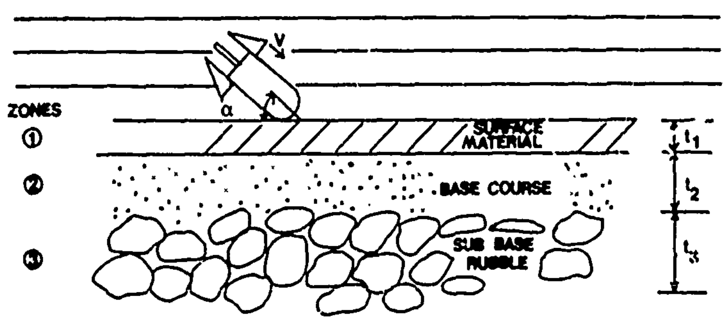
Impact Angle - α, maximum of 60° (from horizontal) governed by delivery possibilities;

Impact Velocity - v, varies from 600 to 900 feet per second;

Surfacing Material - Zone 1: Rigid or flexible. Rigid surface designed to represent conventional runway; flexible surface designed to represent redundant surface.

Base Course - Zone 2: Materials to be comparable and compatible with anticipated repair backfill materials. Thickness based upon strength requirements to support aircraft loads and impart second shock loading at rubble zone in resonance with bomb's response to initial impact. Separation between zone 1 and 2 must be maintained to prevent material migration;

Sub-base - Zone 3: Individual pieces to be twice the diameter of the threat weapon. Depth of layer based upon weapon impact parameters and decelerations. Impact angles will be considered between the threshold for ricochet from surface ($\alpha_{RS} \approx 40°$) and delivery limited ($\alpha_{DL} \approx 60°$). Thickness and hardness of the layer to be determined from weapon characteristics and expected velocity when zone 3 is encountered.



DESIGN CONSIDERATIONS

① CONVENTIONAL RIGID (OR FLEXIBLE BASED UPON COST) DESIGN.

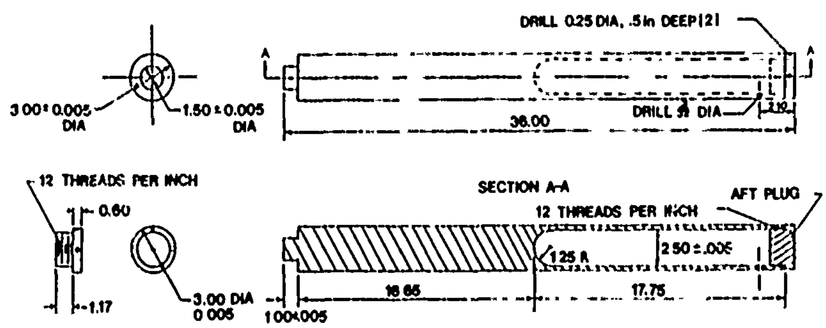
② STRENGTH AND MATERIALS COMPARABLE AND COMPATIBLE WITH BACKFILL MATERIALS USED IN RRR PROCEDURES. t_2 BASED ON NATURAL FREQUENCY OF WEAPONS, IMPACT VELOCITY AND DECELERATION.

③ ROCK RUBBLE SUB-BASE DESIGNED TO DEFEAT WEAPON THREAT WITH RESIDUAL VELOCITY AFTER PENETRATING t_1 AND t_2.

FIGURE 1. DAMAGE-RESISTANT RUNWAY CONCEPT.

Weapon Response

Dominant response frequencies have been measured for runway penetrators impacting concrete targets. The penetrator shown in Figure 2 was instrumented as shown in Figure 3 and impacted with concrete targets in reverse ballistic testing at Eglin [4]. Strain data were analyzed using Fast Fourier techniques to determine dominant frequencies. Results from the analysis are shown in Figure 4. The first three natural frequencies of the penetrator in a preliminary analysis were determined using a three-degree-of-freedom lumped mass model. Frequencies determined analytically are also shown in Figure 4. Natural frequencies of 2108, 3292, and 7791 hertz correspond to natural periods of 0.47, 0.30, and 0.13 milliseconds. For impact velocities below 1000 feet per second into concrete sections approximately one foot thick, the penetrator is experiencing high impact loadings throughout the time period of maximum response which means the maximum response is the same as if the load duration had been infinite. Larger class weapons such as the 750-pound general purpose bomb have natural periods in the 2 to 5 millisecond range. Thus, at higher impact velocities, larger weapons can penetrate thin surfaces before ever reaching maximum response. However, the process of penetrating a series of properly spaced hard layers of penetration barriers imposes a system of pulsating forces on the weapon. Referring to the concept of dynamic load factors presented in Reference 5, it can be seen that the maximum response increases tremendously when loads pulsate at frequencies near the natural frequency of the structural system. Figure 5 compares the dynamic load factor (DLF) with the ratio of load frequency (Ω) to structural frequency (ω) for sinusoidal loads. The proposed damage-resistant runway concept will take advantage of the dynamic response characteristics of the weapon threat and use spaced, hardened layers to impose pulsating loads into the penetrator. Although preliminary analysis has proven the concept feasible, more refined analysis techniques will be applied during the actual design of the concept.



ALL DIMENSIONS IN INCHES

FIGURE 2. TEST ITEM.

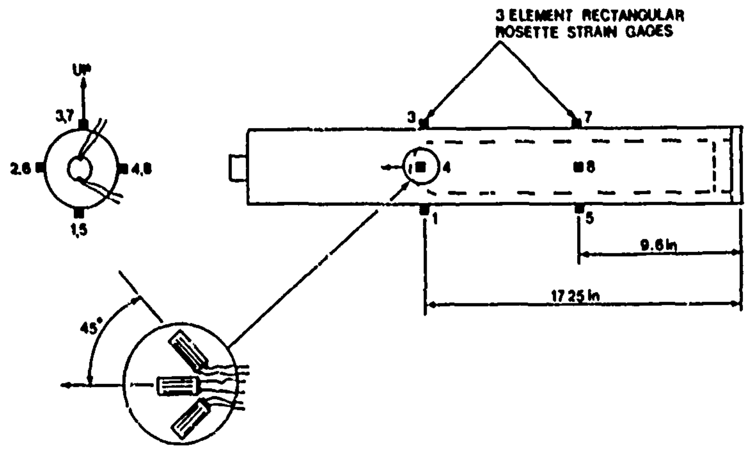


FIGURE 3. STRAIN GAGE CONFIGURATION, SLED TESTS NO. 2 THROUGH 4.

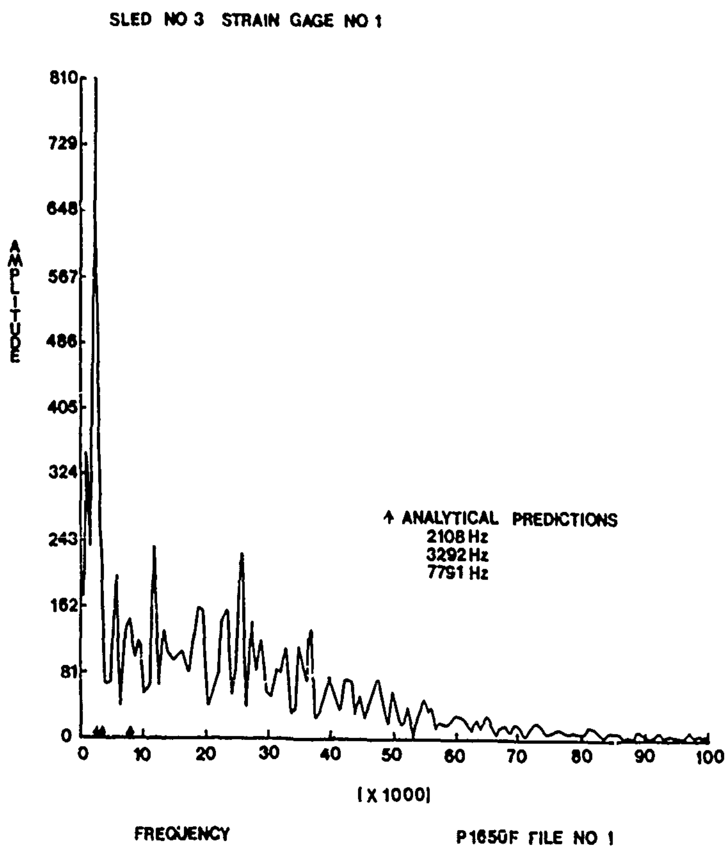


FIGURE 4. SLED 3 FREQUENCY ANALYSIS, STATION 1, GAGE 1.

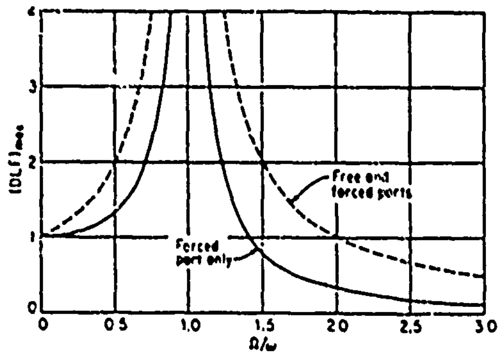


FIGURE 5. MAXIMUM DYNAMIC LOAD FACTOR FOR SINUSOIDAL LOAD $F_1 \sin \Omega t$, UNDAMPED SYSTEMS.

Penetration Modeling

Experiments will be conducted at subscale for economy and ease of testing. Scale modeling has been employed extensively in penetration testing. An entire chapter of Reference 6 is devoted to modeling penetration mechanics. Scale modeling penetration has proven valid, provided physical parameters important to the process are properly scaled in relation to each other.

The Buckingham Pi Theorem will be applied to the penetration conditions illustrated in Figure 1. Important parameters to be considered include weapon impact conditions, target response, and weapon response. Because response of the granular base and sub-base materials is deemed significant for proper modeling, gravity will be included as a parameter, and dissimilar modeling of both the penetrator and pavement surfacing material will be used.

Research Program

Concepts for damage-resistant runways will be developed and tested in research phases which are described below. Once concepts have been verified for subscale models, a test plan will be developed for full-scale test and evaluation.

1. Phase I - Concept Development

Task 1: Two runway pavement sections will be designed for subsequent evaluations of damage resistant concepts: (a) main runway, and (b) redundant surface.

Task 2: A dimensional analysis will be performed for penetration of a weapon into the main runway and redundant surface sections designed in Task 1. The dimensional analysis will be used to determine design subscale experiments to determine penetration characteristics of the pavement sections with and without damage-resistant concepts.

Task 3: An experimental program will be conducted to establish baseline penetration characteristics of the two pavement types before employing damage resistant concepts. Penetration trajectories into targets will be recorded with high speed movies for the simulated full-scale impact conditions shown in Table 1. Target and projectile damage will be recorded following each test.

TABLE 1. TEST CONDITIONS

Impact Angle (Measured from the horizontal)	Prototype Impact Velocity (fps)		
	600	750	900
40°	X	X	X
50°	X	X	X
60°	X	X	X

Task 4: Sub-base rubble zones will be designed to resist penetration by the weapon threat. Designs will be based upon impact conditions listed in Table 1, weapon characteristics, penetration analysis, and results from Task 3 testing.

2. Phase II - Concept Verification

A sub-scale test program will be conducted to verify penetration resistance of pavement sections designed in Task 4. Testing will follow conditions and procedures used in Task 3. Each condition will be tested twice. Data will be recorded similar to Task 3 testing. Designs will be modified during testing as necessary for improved performance.

3. Phase III - Follow-on Development

Based on the results of Phases I and II above, a test program will be developed for full-scale testing of damage resistant runway concepts. This test program will include construction of target runway sections, both conventional and hardened. Live bombs will be air-delivered onto the sections and results will be compared to verify the reduction in damage in the hardened runway versus the conventional runway.

SUMMARY

The Air Force Engineering and Services Center is performing a research effort to develop a concept for construction of runways that are resistant to conventional bomb damage. The concept being investigated consists of using a layer or layers of boulders in a flexible pavement's subbase course to disrupt penetration paths or to cause weapon malfunction. The research is expected to result in a payoff in the late 1980s.

REFERENCES

1. Farmbrough, J. S., "Operation Annabelle," Royal Engineers Journal, 90, February 1976.

2. "Shielding Methodology for Conventional Weapons," U.S. Army Engineer Waterways Experiment Station, January 1980.

3. Austin, C. F., Halsey, C. C., and Berry, S. L., "Full-Scale Penetration Into Semiconfined Diorite Boulders by a Semi-Armor Piercing (SAP) Bomb and a Slender Penetrator," Naval Weapons Center NWC TP 6220, September 1980.

4. Heincker, W. R., "Dynamic Response of a Kinetic Energy Penetrator Vol I, Reverse Ballistic Sled Test of a Kinetic Energy Penetration Into Concrete," AFATL-TR-78-24, Volume I, March 1978.

5. Biggs, J. M., Introduction to Structural Dynamics, McGraw-Hill Book Company, 1964.

6. Baker, W. E., Westine, P. S., and Dodge, F. T., Similarity Methods in Engineering Dynamics, Hayden Book Company, Inc., 1973.